

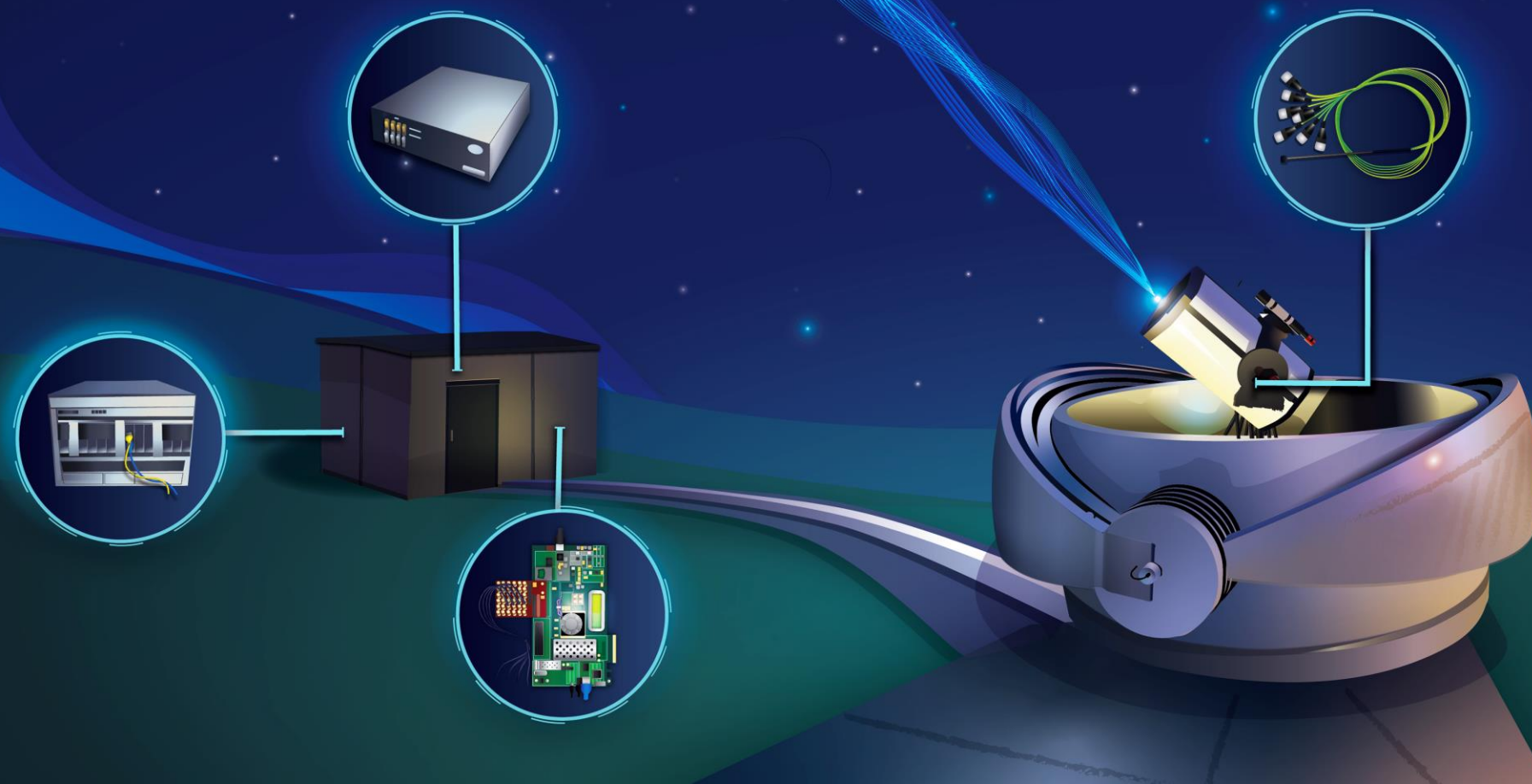


Real-Time Optical Receiver

NASA Technology Transfer Program Webinar

April 2023

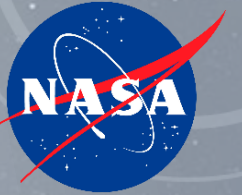
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Graphics by Morgan Johnson

Introduction



- **NASA is using the CCSDS Optical Communications High Photon Efficiency (HPE) waveform on future missions: Optical Artemis-2 Orion (O2O), Psyche**
 - PPM: 4, 8, 16, 32, 64, 128, 256
 - Slot widths: 512 ns - 125 ps
 - Maximum data rate: ~2 Gbps
- **NASA Glenn is building a photon-counting ground receiver compliant with the CCSDS Optical Communications HPE standard**
 - PPM: All
 - Minimum Slot width: 500 ps
 - Maximum data rate: 533 Mbps
- **Goals:**
 - Utilize commercial off the shelf (COTS) components
 - Demonstrate with O2O at the NASA Goddard Low Cost Optical Terminal (LCOT) ground station
 - Transfer technology to commercial company

RealTOR – Subsystems Under Development



SNSPDs¹

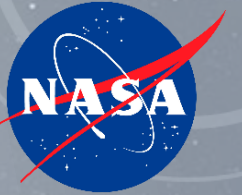
Fiber Interconnect

FPGA²-based
Receiver

FPGA²-based Transmitter

1. Superconducting nanowire single photon detectors
2. Field programmable gate array

Receiver Subsystems Under Development



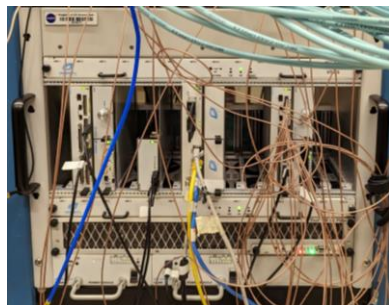
Fiber Interconnect:

- Photonic lantern (one multimode fiber input to 7 FMF outputs) or FMF
- Input fiber core size, number of outputs, and output fiber core size scalable to application
- In house prototyping capability; development partnership with University of Sydney



Single Photon Detector:

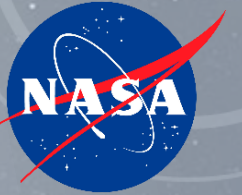
- COTS detectors, portable, rack-mounted
- Array of FMF coupled single-pixel detectors sharing one cryostat or single monolithic 16-channel array
- Continuous operation, includes amplifier electronics, 60-80% efficient



FPGA-based Receiver:

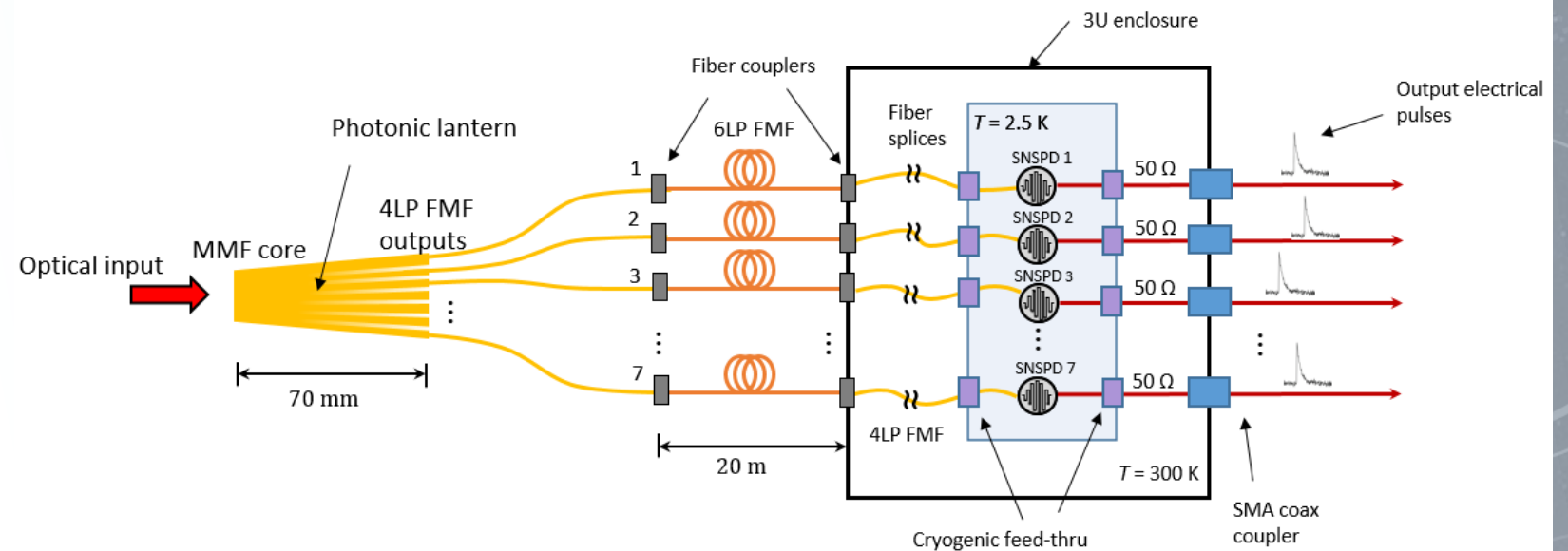
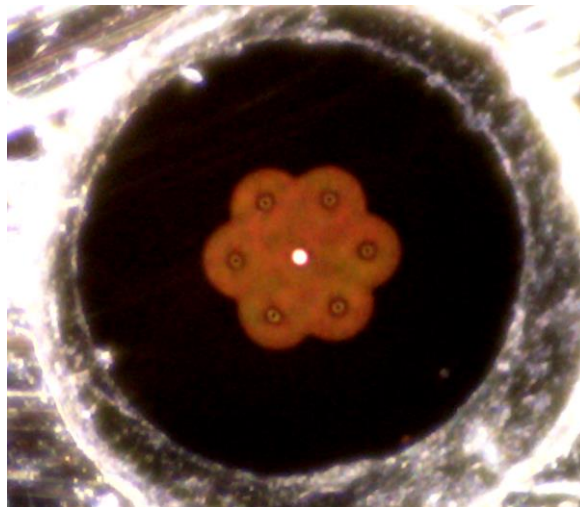
- 1 ADC per detector channel; digital detector channel combining
- Real Time processing; COTS development platform
- Compatible with CCSDS downlink optical waveform (high photon efficiency)
- FPGA VHDL/Verilog receiver code will be released

Photonic Lantern + 7 Single Element Detectors

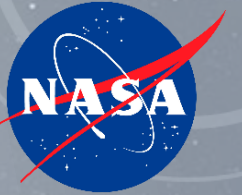


Photonic Lantern:

- FMFs:
 - 20 μm graded-index core
 - 4LP, 6-mode
- MMF input:
 - 55 μm
 - 42 total modes



FMF + 16-Channel SNSPD Array

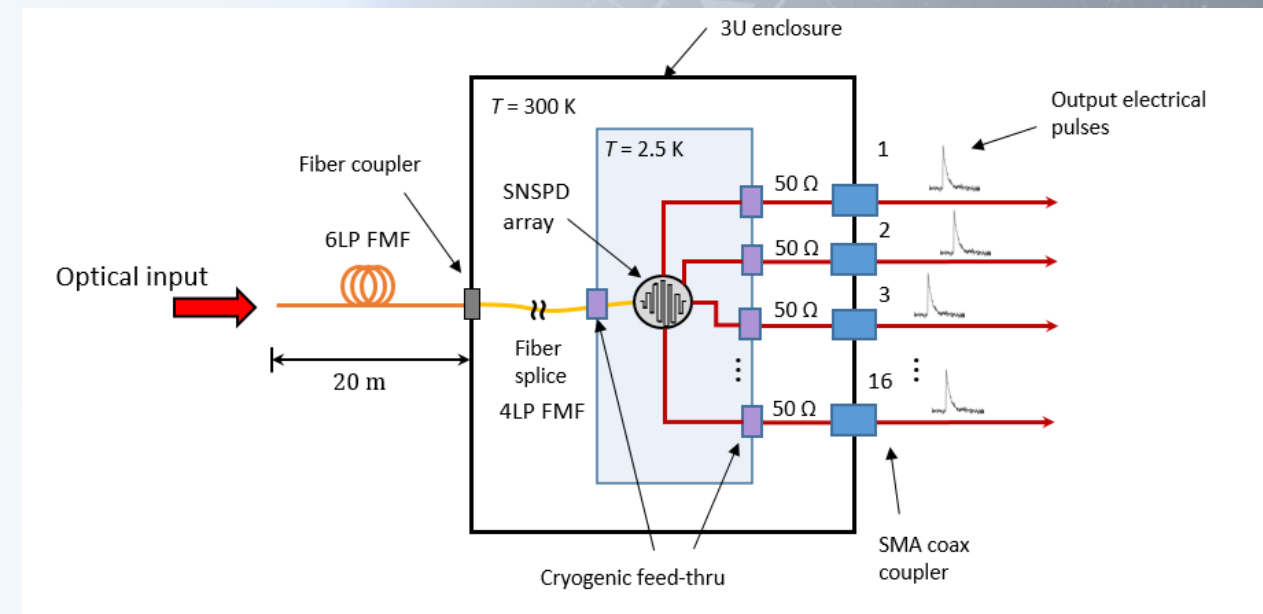
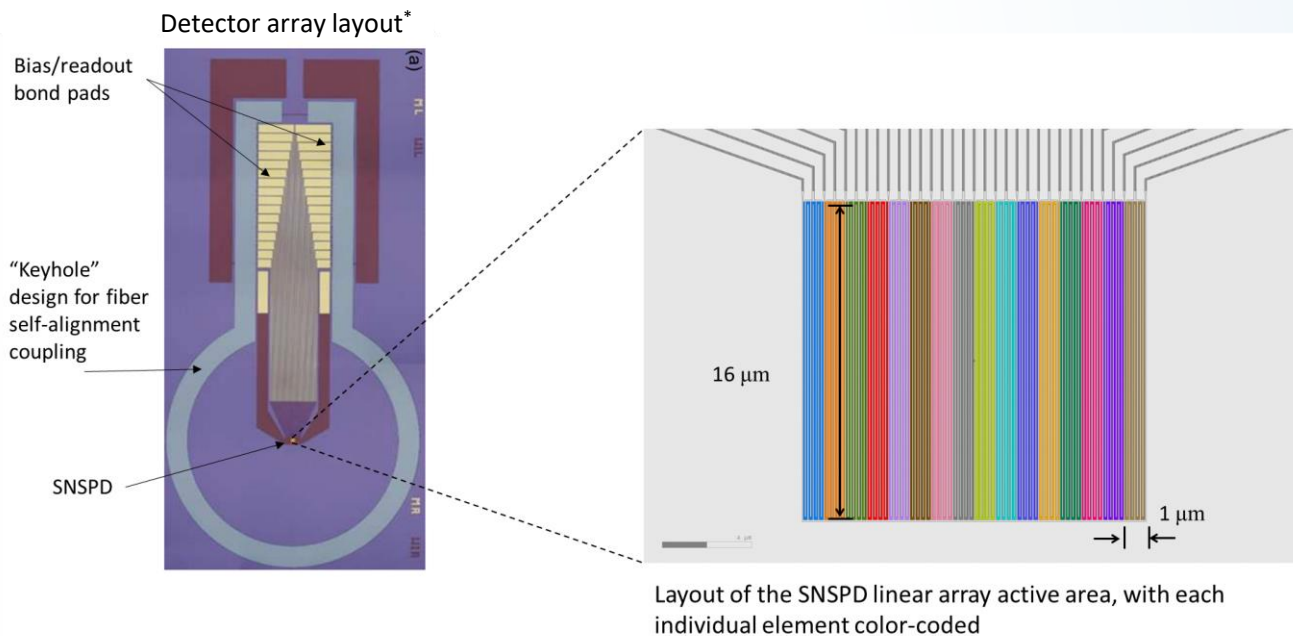


FMF #1 (coupled to SNSPD array):

- 20 μm graded-index core
- 4 LP, 6-modes

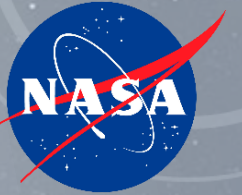
FMF #2 (20 m system input):

- 25 μm graded-index core
- 6 LP, 10-modes

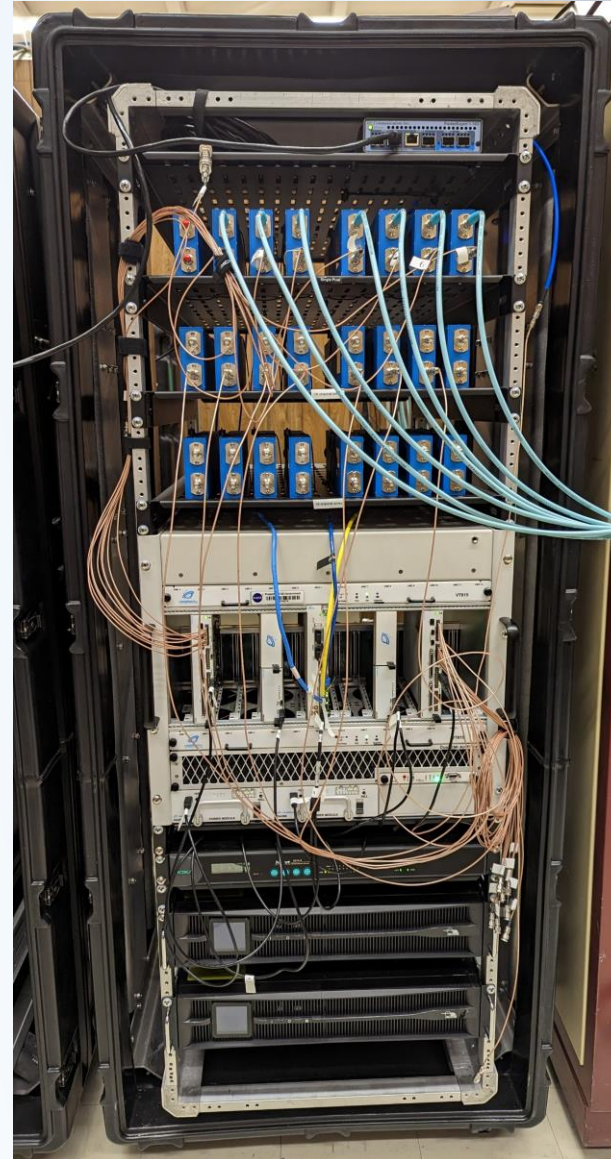


*Rambo, T. M., Conover, A. R., and Miller, A. J., "16-element superconducting nanowire single-photon detector for gigahertz counting at 1550-nm," (2021). <https://arxiv.org/abs/2103.14086>

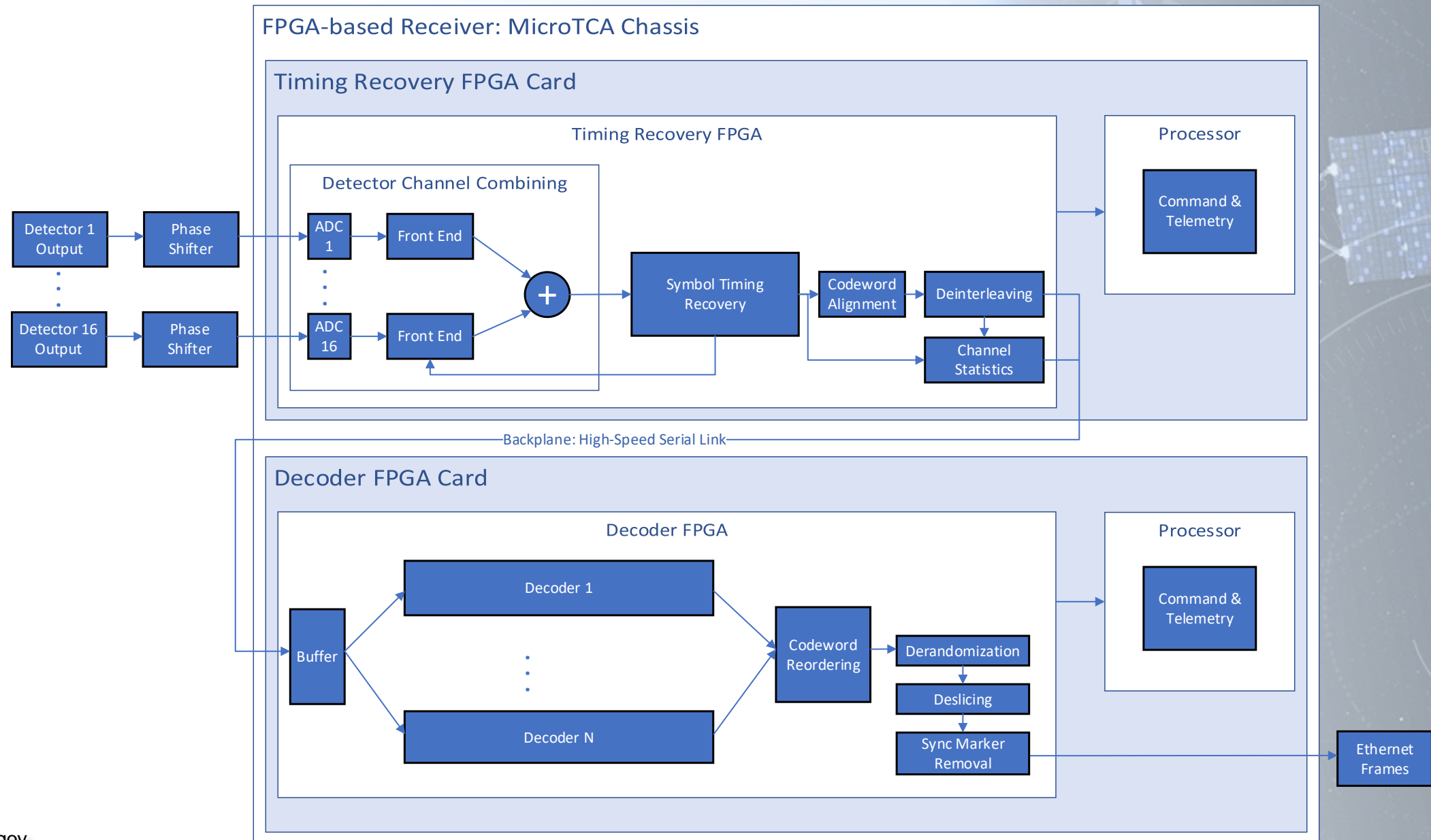
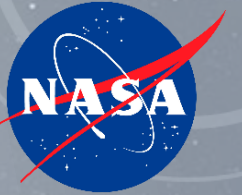
FPGA-based Receiver



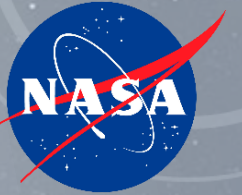
- COTS MicroTCA development platform
- Command/telemetry interface is through HTTP interface built on Space Telecommunications Radio System Architecture



FPGA-based Receiver



Timing Recovery FPGA

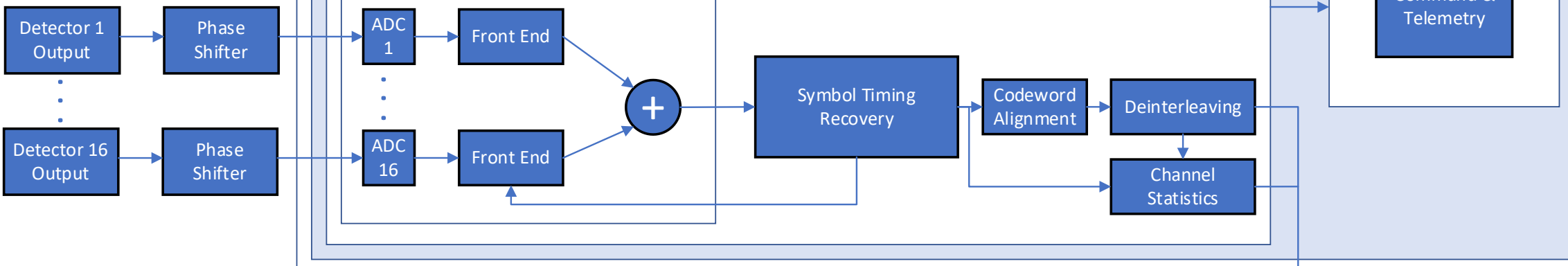


FPGA-based Receiver: MicroTCA Chassis

Timing Recovery FPGA Card

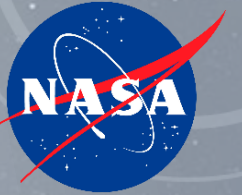
Timing Recovery FPGA

Detector Channel Combining

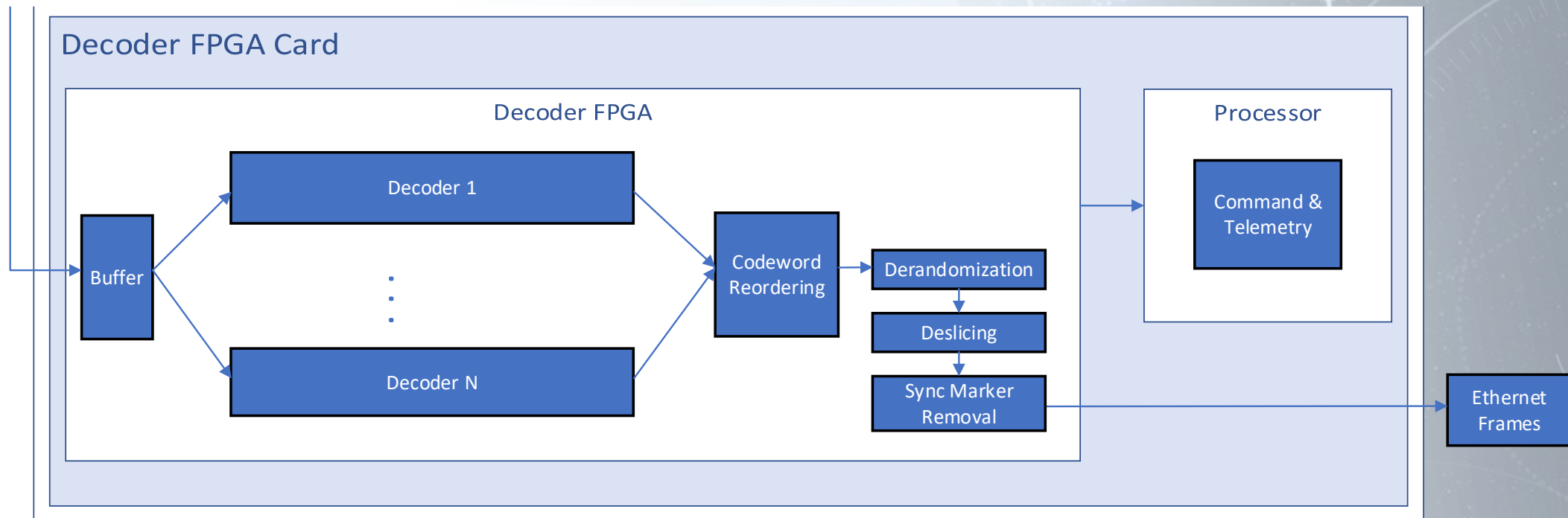


- **Xilinx Radio Frequency System-on-Chip (RFSoc) FPGA with 16 ADCs**
- **Time alignment with mechanical phase shifters**
- **Performs channel combining, photon counting, symbol timing recovery, codeword alignment, convolutional deinterleaving**
- **Calculates channel statistics to send to Decoder FPGA**

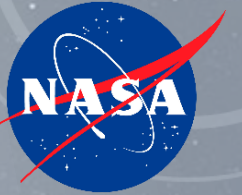
Decoder FPGA



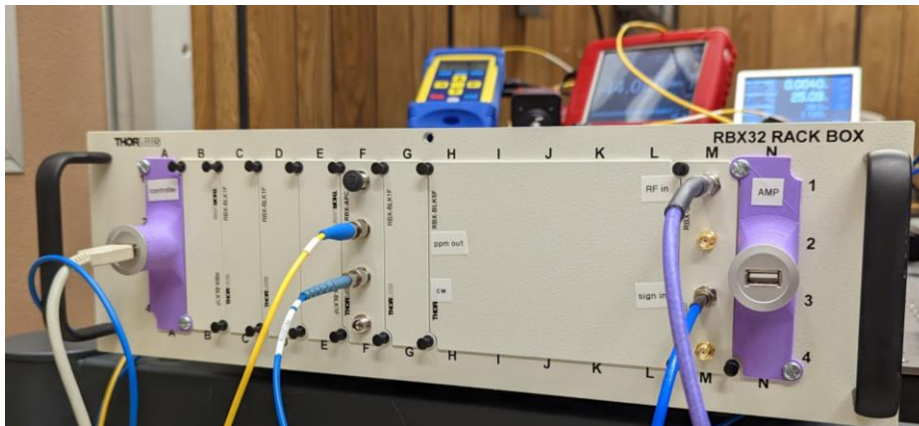
- Calculates 8-bit slot log-likelihood ratios
- Performs BCJR iterative decoding and queuing and reordering for multiple decoder instances
- Test mode allows independent characterization of decoder FPGA




Test Transmitter





- Transmitter FPGA implements the CCSDS HPE standard
- Modulator box performs optical pulse carving with 2 Mach-Zehnder modulators





Patent PortfolioSoftware CatalogSpinoffContactResources ▾Log In



Electronics And Electrical Power

CCSDS Optical Communications High Photon Efficiency Telemetry Signaling Transmit Waveform VHDL/Verilog

(LEW-20090-1)

Overview

This technology is a VHDL and Verilog implementation of the Consultative Committee for Space Data Systems (CCSDS) Optical Communications High Photon Efficiency Telemetry Signaling waveform. The CCSDS 142.0-B-1 Blue Book from August 2019 is implemented. The implementation includes a data source, transfer frame synchronization marker attachment, slicer, randomizer, cyclic redundancy check, termination bit attachment, convolutional encoder, code interleaver, accumulator, pulse position modulation (PPM) symbol mapper, channel interleaver, codeword sync marker attachment, symbol repeater, slot mapper, and guard slot insertion.

Request Software

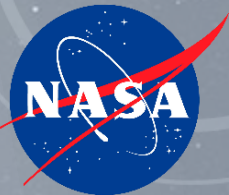
Software Details

Category	Electronics and Electrical Power
Reference Number	LEW-20090-1
Release Type	U.S. and Foreign Release
Operating System	Windows

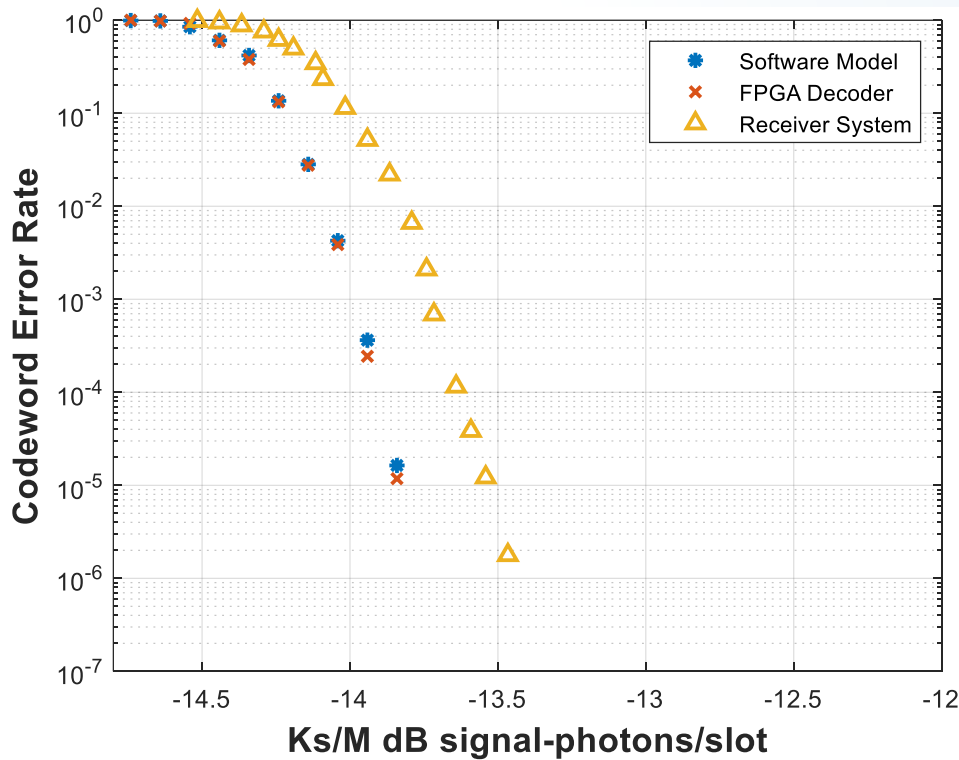
Contact Us About This Technology

Glenn Research Center
grc-sra-team@mail.nasa.gov

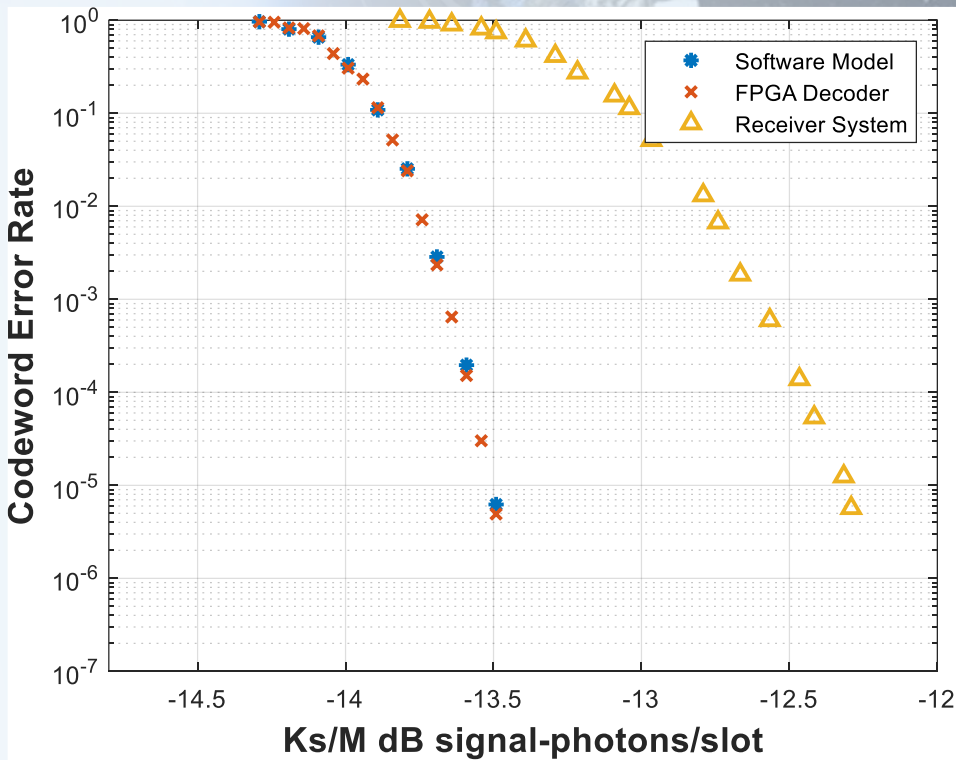
Codeword Error Rate Curve Results – PPM-16, Code Rate 1/3, 133 Mbps



Photonic Lantern + 7 Single-pixel Detectors



FMF + 16-pixel Detector Array



When operating where the photonic lantern numeric aperture is matched to turbulence conditions, it is expected that both architectures will perform similarly.

Detector Jitter & FPGA Implementation Loss (dB)		Fiber & Detector Loss (dB)		Measured K_b at 10^{-5} CWER (dB photons/slot)		Required Input Power at 10^{-5} CWER (dBm)	
PL	A	PL	A	PL	A	PL	A
0.3	1.2	8.0	3.2	-27.2	-22.0	-72.2	-75.5

Demonstration at NASA GSFC LCOT³



SNSPDs¹

Fiber Interconnect

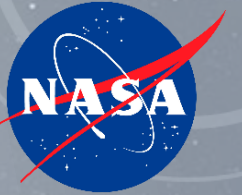
GSFC LCOT³: dome, telescope, back-end optics, pointing & tracking

FPGA²-based Receiver

FPGA²-based Transmitter

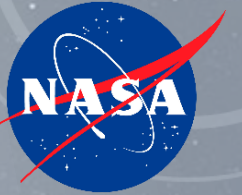
1. Superconducting nanowire single photon detectors
2. Field programmable gate array
3. Low Cost Optical Terminal –GSFC collaboration

Conclusion



- A photon-counting ground receiver has been developed and tested for several CCSDS HPE modes.
 - Two fiber/detector architectures were prototyped
- When operating in an optical ground station where the photonic lantern numeric aperture is matched to turbulence conditions, it is expected that both architectures will perform similarly.

Next Steps



NASA Space Act Agreement

- Reimbursable
- Non-reimbursable

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